

AXIAL FANS WITH AN EXTENDED STEADY OPERATION REGION

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Translation of "Osevyte Ventilyatory s Rasshirennoy Oblast'yu Ustoychivoy Raboty," in Aerodinamika lopatochnykh mashin (Promyshlennaya Aerodinamika, No. 29, 1973), edited by A. S. Ginevskiy, Moscow, "Mashinostroyeniye" Press, pp. 88-97

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16. Abstract The control characteristics of a single-stage axial fan with meridional flow acceleration in the rotor are discussed. The rotor is equipped with a flow separation prevention device in order to extend the region of steady operation of the fan. The effects of two different flow separation preventing devices on the control characteristics of two-stage axial fans are analyzed when the rotor blades in the fans are set at different angles.			
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The characteristics of axial fans under certain operating conditions, as we know, suffer a discontinuity or have a pressure maximum. Here a region in which operation as a rule is unacceptable in terms of stability appears in the characteristic. Problems of unstable operation are examined in several studies [1, 3-6].

Besides the method of extending the steady-operation region examined in [6] by using the separator proposed by L. Ye. Ol'shteyn and K. A. Ushakov, in several cases the annular device in the fan housing proposed by V. F. Knyazev can be more effective.

Let us look at two methods of eliminating the instability: a) using a separator and an annulus for a two-stage axial fan with different rotor blade setting angles and regulation by rotating the blades of an intermediate guide; and b) by using an annulus for a single-stage axial fan with meridional acceleration of the flow over wide range of regulation by rotating the inlet guide.

The operation of the annulus device is based on "removing" the separation zones through the annulus in the fan housing. Naturally, here the pressure in the space into which the separation zones are removed must be less than the pressure where they are formed. The separation zones arise in the blade rim of the rotor and usually do not extend beyond the limits of the trailing edges of the blade.

If the line in which the fan is operating is on the suction side, the annulus device obviously cannot function. But if the line is on the compression device, the pressure at the wall of the fan housing varies from a value that is smaller than the

pressure in the space (atmospheric) surrounding the housing to a higher pressure. Therefore, a location in the housing can be found where the pressure for a specific fan operating regime is equal to the atmospheric pressure. Here the volume flow of the air through the annulus will be zero. We know that separation zones appearing in the region of pressure maximum or at discontinuity of the characteristic. If we select the location of the annulus so that the zero volume flow through it occurs close to the maximum fan efficiency regime, which lies to the right of the pressure maximum on the descending branch of the characteristic, we will achieve a certain automatic action of the annulus.

Naturally, for effective functioning of the annulus a definite amount of air must pass through it, and the volume flow of the air depends also on the geometry of the annulus. Experience /92 has shown that the annulus in the housing must lie in the region of the rotor blades. Here even for a zero volume flow through the annulus the operating conditions of the fan deteriorate owing to a sharp increase in the radial clearance between the blades and the housing in the region of the annulus. Therefore the width of the annulus must be as small as possible and the required volume flow through it must be ensured also by selection of the diffuser in the body of the housing.

The optimal annulus geometry and its location can now be quite reliably determined experimentally, especially for the case of the unusual fan layout. However, the annulus device with air discharge into the ambient space cannot be used when the fan is operating in suction. The separator, bypass, and other similar devices function independently of the location of the line with respect to the fan, but for large angles of rotor blade setting $\theta_K > 30^\circ$, the separator, for example, becomes low in efficiency, while the annulus device functions quite effectively.

1. K-70m Fan With Annulus /89 Antiseparation Device (ASD)

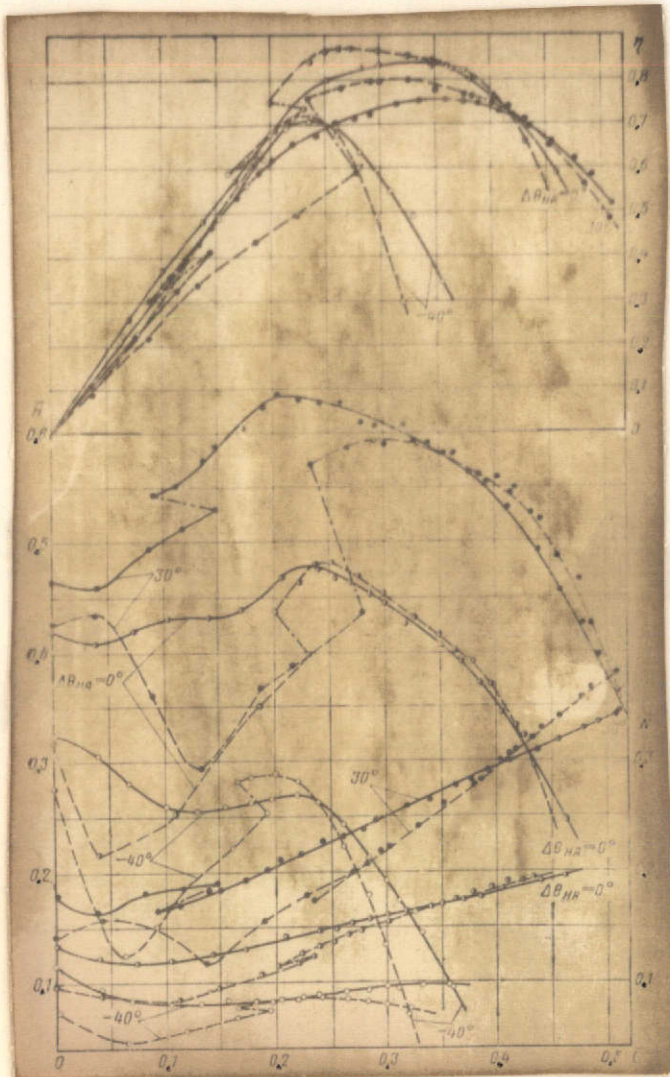


Fig. 1. Characteristics of K-70m fan with annular antiseparation device (solid lines) and without it (dashed lines) for three values of $\Delta\theta_{HA}$, constant value $\theta_K = 43^\circ 20'$ and $\theta_{HA \text{ in}} = 97^\circ 30'$.

The optimal geometry of the annulus antiseparation device was developed for a model of the K-70 fan; its aerodynamic layout and characteristics are given in the study [2] under the designation VM-2. Fig. 1 gives the characteristics of the full-sized K-70m fan¹, with diameter $D = 700$ mm for three setting angles of the inlet guide, $\Delta\theta_{HA} = 0, +30^\circ$, and -40° , and for the same rotor blade setting $\theta_K = 43^\circ 20'$. The setting angle of the inlet guide is determined with formula

$$\Delta\theta_{HA} = \theta_{HA} - \theta_{HA \text{ in}}$$

The layout of the fan and the parameters of the ASD are shown in Fig. 2. As we can see, the operation of the annular

¹ The full-scale model of the K-70m fan with meridional flow acceleration differs in its geometry from the model by the modified inlet guide; this device permits total closure of the flow-through section, and another difference is the profiled blades of the rotor (these blades are of the sheet type in the model).

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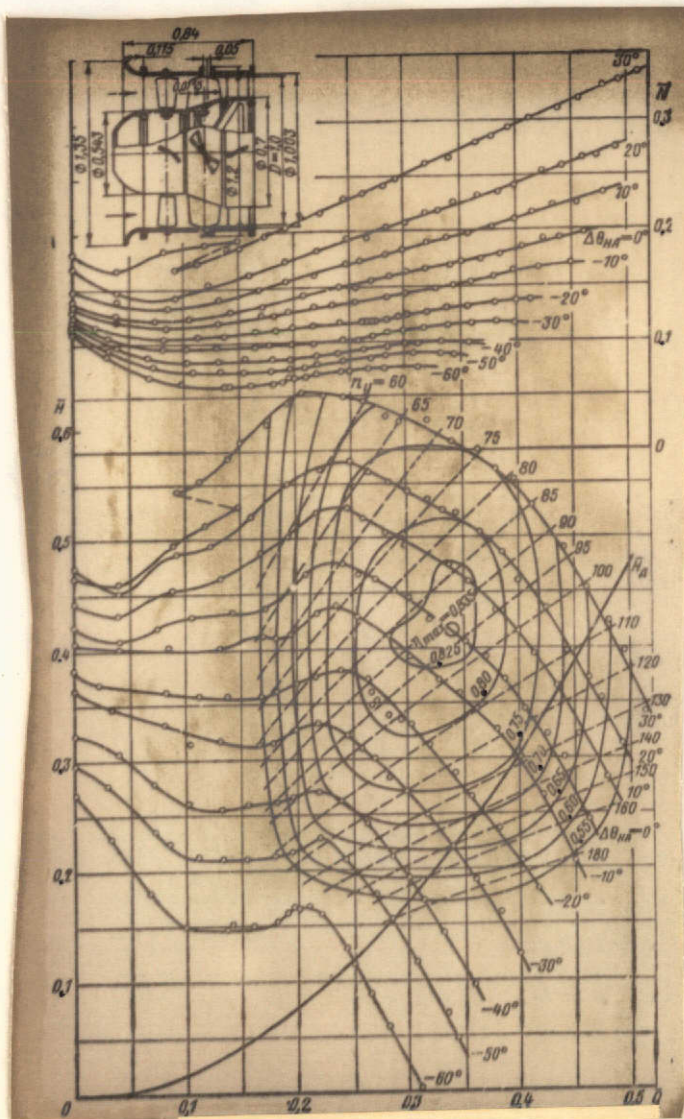


Fig. 2. Aerodynamic layout and characteristics of K-70m single-stage axial fan with meridional acceleration, with annular anti-separation device, $\theta_{HA \text{ in}} = 97^\circ 30'$.

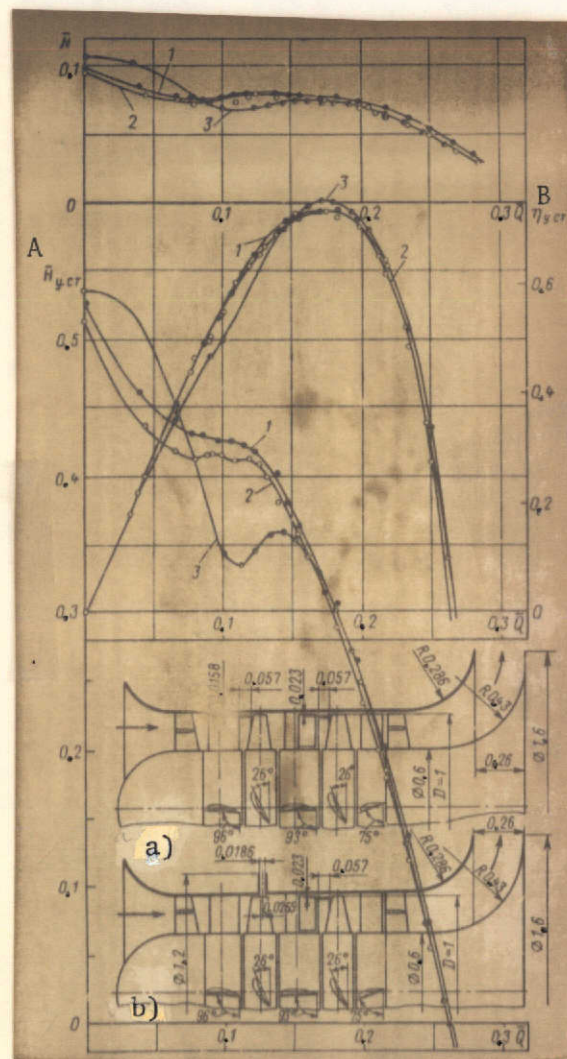


Fig. 3. Comparison of the efficiency of antiseparation devices for installation with K-111 model two-stage fan, with $D = 700$ mm and $n = 900$ rpm:

1. with separator
2. with annulus and separator
3. without antiseparation device

KEY: A. $\bar{h}_{\text{layout, static}}$
B. $\eta_{\text{layout, static}}$

ASD is highly efficient and permits functioning over a wide range of pressures all the way to $\bar{h} = 0.6$, but leads to some reduction in the maximum fan efficiency from 0.865 to 0.835.

Also worthy of note is the considerable effect of the annular ASD on the shape of the characteristic in its right branch during regulation, which was not observed earlier in fans with the usual layout. The regulatory characteristics of the K-70m single-stage fan, when an annular ASD is present, throughout the entire tested range of setting angles of the guide blades are shown in Fig. 2. Also given in this figure is the parabola of the dynamic pressure of the fan $\bar{H}_p(\bar{Q})$, which makes it possible to construct approximate characteristics of the placement of this fan with inlet or discharge components (connections and diffusers), whose loss coefficient is known: $\bar{H}_{\text{layout}} = \bar{H} - \zeta \bar{H}_p$; $\eta_{\text{layout}} = \bar{H}_{\text{layout}} \bar{Q} / \bar{N}$, where $\zeta = \Delta H_{\text{layout}} / H_p$; and ΔH_{layout} are the pressure losses in the components of the device.

2. K-111 Two-Stage Fan With Two Types of ASD

The use of the above-described annular ASD for both stages of a two-stage fan with the line on the compression side is inadvisable for the reason that the volume flows through the annulus over the second stage will be observed in all operating regimes, since here the pressure is always higher than the atmospheric value. 93 This leads to considerable reduction of efficiency in normal operating conditions.

Introducing special devices for closing and opening the annulus over the second stage in certain operating conditions complicates the fan and deprives the annular ASD of one of its key features -- automaticity.

In these cases we can use combination ASD: annular ASD over the first stage and a ASD design of the second stage that would not require the "removal" of the separation zones into the ambient space. Since the annular ASD is an effective and very simple device, this combination can prove to be advisable.

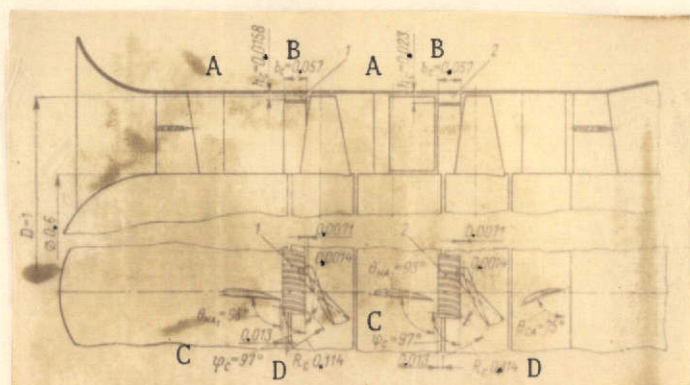


Fig. 4. Layout of separators ahead of rotors and mean dimensions of separators:

1. separator 1, $\bar{h}_s = 0.0158$, $\bar{d}_s = 0.057$,
 $\bar{r}_s = 0.114$, $z_s = 200$
2. separator 2, $\bar{h}_s = 0.023$, $\bar{b}_s = 0.057$,
 $\bar{r}_s = 0.114$, and $z_s = 200$ (dimensions
are given in fractions of fan diameter).

KEY: A. h_s C. ψ_s
B. b_s D. R_s

Fig. 3 gives the aerodynamic layouts of the devices and their characteristics with respect to static pressure with K-111 two-stage fans with ASD in two design executions: a) with the separators in front of the first and the second stages; and b) with the annulus of the first stage and the separator over the second. The geometrical parameters of the annulus are presented in the same figure, while the parameters of the separator are shown in greater detail in Fig. 4.

For comparison, Fig. 3 gives the characteristic of the K-111 fan without the ASD. As we can see, both types of ASD function efficiently. However, the ASD with only the separators somewhat more effectively equalizes the characteristic and makes it possible to achieve somewhat higher pressure in the zone of low and zero capacities. In terms of efficiency, both ASD modifications are virtually equivalent.

Figs. 5-7 give the regulatory characteristics of a two-stage fan layout with separator ASD obtained by rotating the blades of the intermediate guide within the limits $\Delta\theta_{HA} = +30^\circ + -40^\circ$ for the setting angle of rotor of blades $\theta_{K1,2} = 18^\circ 30'$ (in Fig. 5),

$\theta_{K1,2} = 23^\circ 30'$ (in Fig. 6), and $28^\circ 30'$ (in Fig. 7). For comparison, the characteristics without ASD if $\Delta\theta_{HA} = 0^\circ$ are shown by dashed lines.

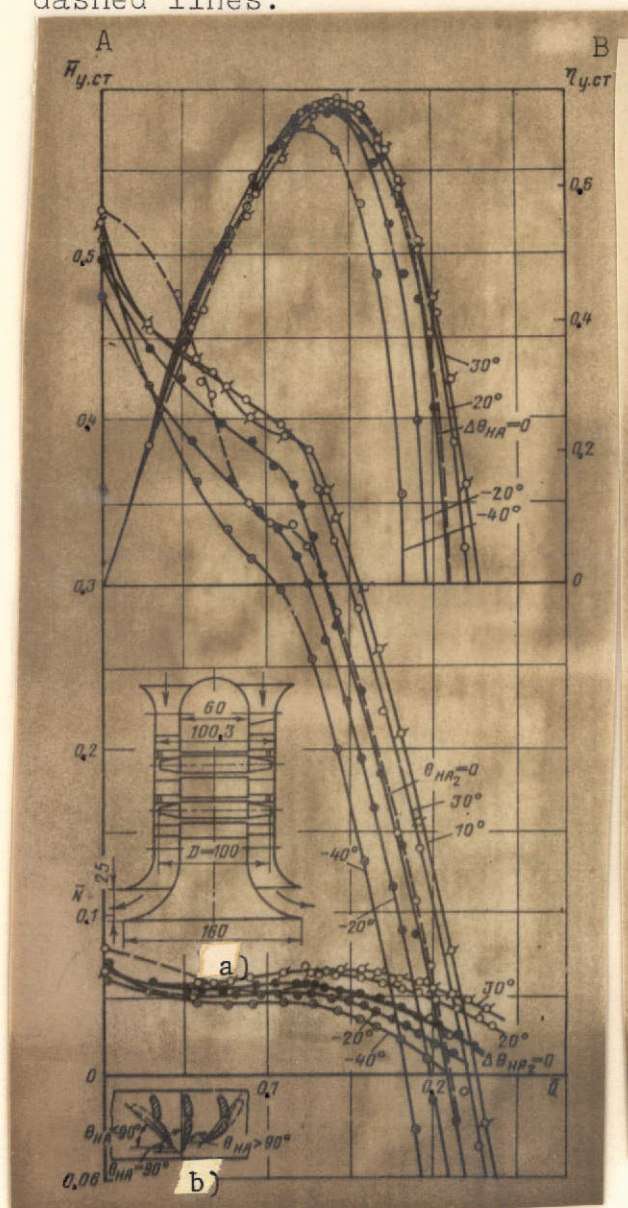


Fig. 5. Aerodynamic characteristics of layouts with K-111 two-stage fan, with $D = 700$ mm and $n = 900$ rpm and $\theta_{HA\text{ in}} = 93^\circ$ with separators 1 and 2 (solid lines) and without separators (dashed lines); $\theta_{K1,2} = 18^\circ 30'$:

[Keys of Figs. 5 and 6 on following page]

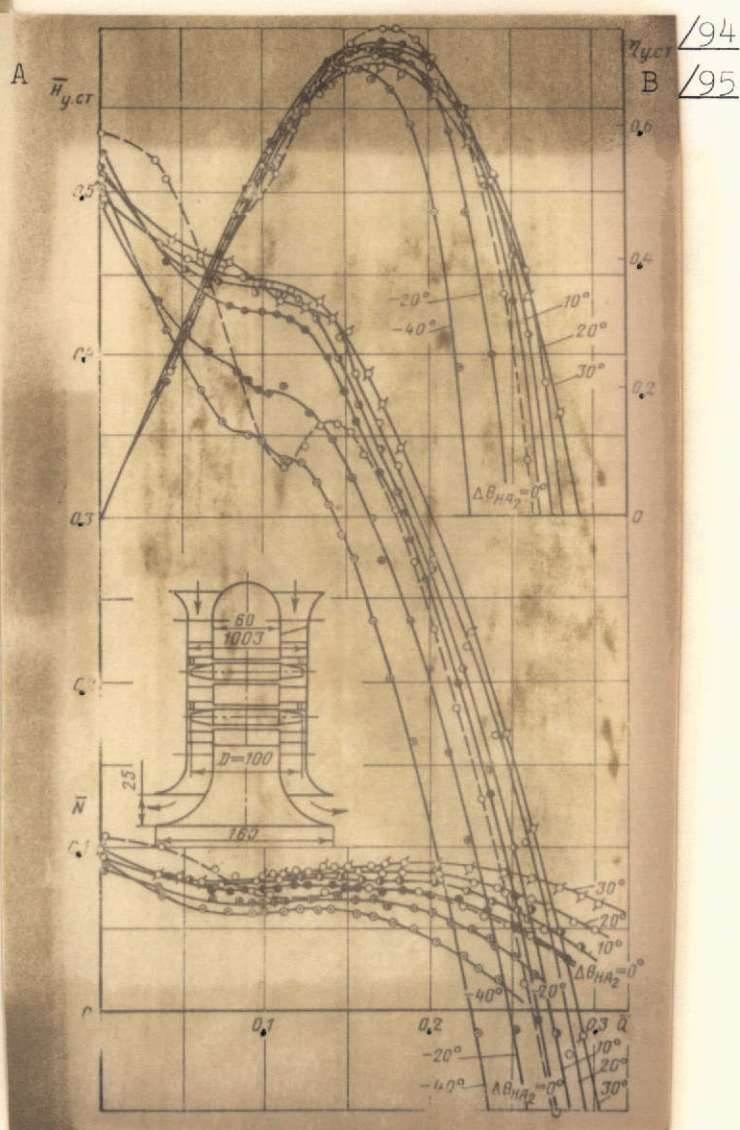


Fig. 6. Aerodynamic characteristics of layout with K-111 two-stage fan, with $D = 700$ mm and $n = 900$ rpm and $\theta_{HA2\text{ in}} = 93^\circ$ with separators 1 and 2 (solid lines) and without separators (dashed lines); $\theta_{K1,2} = 23^\circ 30'$.

Key of Fig. 5 on preceding page

a. layout of device

b. measurement of angles during regulation

KEY: A. $\bar{H}_{\text{layout static}}$

B. $\eta_{\text{layout static}}$

KEY of Fig. 7

A. $\bar{H}_{\text{layout static}}$

B. $\eta_{\text{layout static}}$

As we can see, in all cases it was possible to achieve characteristics of the layout with a K-111 two-stage fan ensuring steady operation throughout the range of capacities, beginning with the zero value.

Key of Fig. 6 on preceding page

KEY: A. $\bar{H}_{\text{layout static}}$

B. $\eta_{\text{layout static}}$

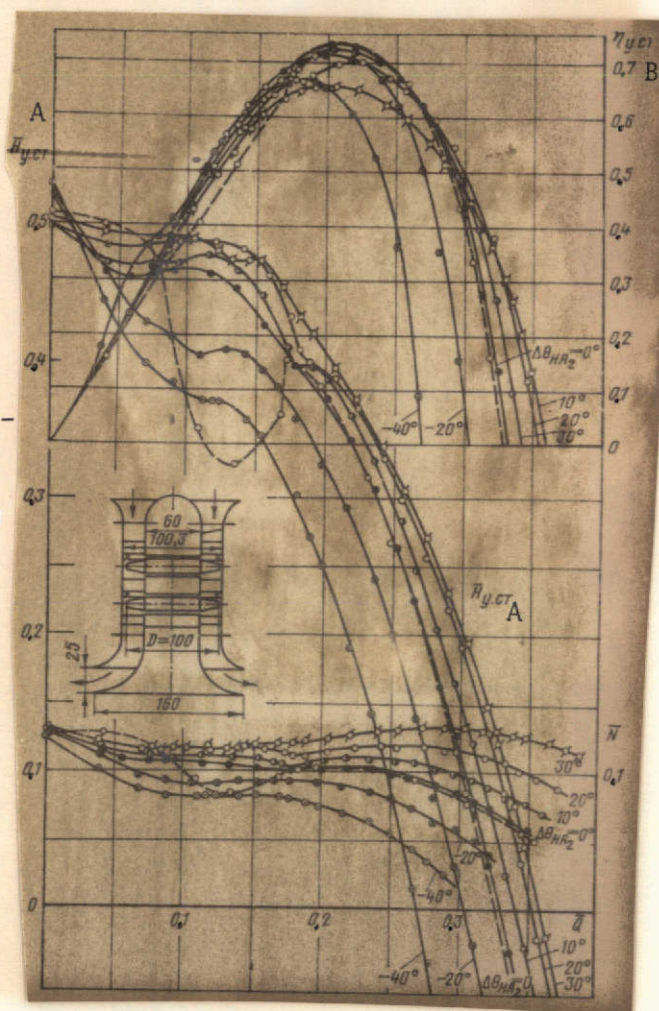


Fig. 7. Aerodynamic characteristics of layout with K-111 two-stage fan, with $D = 700$ mm and $n = 900$ rpm, $\theta_{HA_2 in} = 93^\circ$ with separators 1 and 2 (solid lines) and without separators (dashed lines): $\theta_{K1,2} = 28^\circ 30'$

REFERENCES

1. Borisov, G.A., Lokshtanov, Ye. A., and Ol'shtein, L. Ye., "Rotating Separation in Axial Fan," Sb. Promyshlennaya aerodinamika [Industrial Aerodynamics, collection of articles], No. 24, Oborongiz, 1962.
2. Brusilovskiy, I. V., "Fans With Meridional Acceleration of Flow," Sb. Promyshlennaya aerodinamika, No. 24, Oborongiz, 1962.
3. Dzidziguri, A. A., and Matikashvili, T. I., Neustoychivaya rabota ventilyatorov i sposoby yeye preduprezhdeniya [Unsteady Operation of Fans and Methods of Preventing It], "Nauka", 1965.
4. Yershov, V. N., Neustoychivyye rezhimy turbomashin [Unsteady Turbomachine Operating Conditions], "Mashinostroyeniye", 1966.
5. Kazakevich, V. V., Avtokolebaniya (pompazh) v ventilyatorakh i kompressorakh [Natural Oscillations (Surging) in Ventilators and Compressors], Mashgiz, 1959.
6. Ushakov, K. A., and Bushel', A. R., "Eliminating Instability of Operation of Axial Fans by Using Separators," Sb. Promyshlennaya aerodinamika, No. 24, Oborongiz, 1962.